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Abstract
Minimization of methane leakages in biogas plants is a challenge to ensure the environmental benefit of anaerobic digestion systems. Current estimation methods highlight uncertainties mainly due to spatial and temporal variations of leakages. Therefore, a real-time detection and quantification technology would be the achievement of a great bet to limit such uncertainties. The presented novel method approaches this optimum. The technique is based on a turbulent gas flow estimator model adapted to infrared image sequences. After a lab calibration phase, on-site experiments were conducted to validate the new method and compare its results with traditional measurements techniques.

Keywords
Methane emissions, infrared imaging, optical flow, biogas plant, leak

INTRODUCTION

Targeted benefits of anaerobic digestion through the development of biogas plants are the reduction of methane emissions inherent to conventional manure management, the recycling of organic waste, the contribution to renewable energy, and the substitution of mineral nitrogen by the digestate. To ensure the environmental benefit of anaerobic digestion, biogas leaks should be as low as possible. According to Borjesson & Berglund (2007) leaks of biogas plant are normally less than 2%, but can vary between 0.2% and 13%. To reduce biogas emissions it is important to gather precise knowledge about the biogas leaks occurring in the production chain. Holmgren et al. (2015) showed large variations in the estimation of leaks when comparing more or less classical methods. In this study we propose an alternate approach by extending Optical Gas Imaging (OGI), classically used for detection, to gas leak quantifications. Sandsten & Andersson, (2012) and Shao-hua et al. (2015) developed infrared gas diffusion flow estimators, demonstrating the interest of these new non-intrusive techniques. In the present study, we propose a novel turbulent fluid dedicated optical flow approach to estimate the leaks. For this purpose controlled laboratory experiments and on-site measurements have been carried out.

MATERIALS AND METHODS

Infrared cameras for gas leaks detection

Especially for safety reasons, the use of OGI is frequent in the detection of leaks for the oil and gas industry. This technique is also being developed in the field of biogas plants. OGI is based on infrared absorption of a specific gas of interest. In this study, we used Flir GF320 camera which is largely used for its usability and which provides real time methane leak visualization. Flir GF320 camera's resolution is 320 x 240 pixels at 30 frames per second. Detection threshold is low, about 2.5 Nl/h (B. Thomas et al., 2012). A detection campaign pinpointed more than 60 leaks in 12 different biogas installations. This gave us an overview of the types of leakages encountered in agricultural sector.

New gas leaks quantification method by infrared cameras

The proposed Methane Flow Estimator (MFE) is based on methane clouds velocity and its concentration-length. The velocity vectors field -as shown in figure 1 and corresponding to the gas motion between two consecutive infrared images- is estimated with a turbulent fluid dedicated optical flow approach (P. Héas et al., 2012, 2013). Concentration-length is estimated from pixels' luminance. Therefore, the MFE is a combination of velocity profiles and concentration-length profiles along the gas cloud.

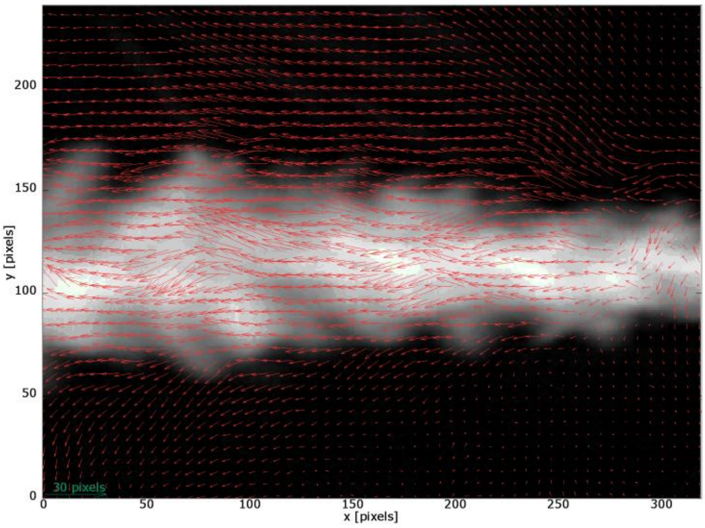

Figure 1. Infrared gas image with superposed velocity vector field.

Lab-scale experiment

The estimator was calibrated and validated in laboratory experiments. Controlled leaks were generated by mixing methane and carbon dioxide with a 60/40 proportion. Two Bronkhorst mass flow meter provided methane and carbon dioxide flow with high accuracy. Leaks were generated in a wind tunnel where the air temperature and wind speed were controlled. After a first campaign of validation in wind tunnel, a series of tests were conducted outdoor with controlled leaks. In the last step of lab-scale experiments, a prototype was developed to improve acquisition conditions.

On-site measurements

On-site campaigns were conducted at a small-scale agricultural biogas plant (150 kWe) located in Brittany (France). Such experiments were carried out to validate the novel method, i.e. OGI extended to quantification thanks to the MFE described above. The validation was done through two complementary approaches, a standard reference method which is bagging and a tracer gas method. Ten leaks were detected around the digester. In this paper, we focused on one leakage located on a digester trapdoor. This leak was chosen to make possible synchronised measurements between OGI+MFE estimation and the bagging technique involving a gas analyser and a hot wire anemometer.

RESULTS AND DISCUSSION

Lab-scale validation

Figure 2A shows estimator accuracy for 12 flows rate generated in the wind tunnel. In these optimal experimental conditions, mean error was of 5% up to 120 l/h. For highest leakages the gas flow was underestimated. This behavior was due to the large gas cloud displacement between two frames (higher than 20 pixels). It's possible to reduce this effect by moving the camera back. Instantaneous gas flow estimation is shown in figure 2B for a fixed flow at 60 l/h. As we can see, the technique exhibits rather low variations of the instantaneous estimated flow. 45 tests were performed to characterize the method in different conditions like background temperature, gas humidity, wind speed, and camera distance. The accuracy of the results is mainly affected by the large displacements and by the difference between background temperature and gas temperature (dT). The sensitivity of the estimator to such operational parameters deducted from the lab is important to be known before an on-site experiment. Hence, we developed a prototype to improve measurements conditions when necessary.

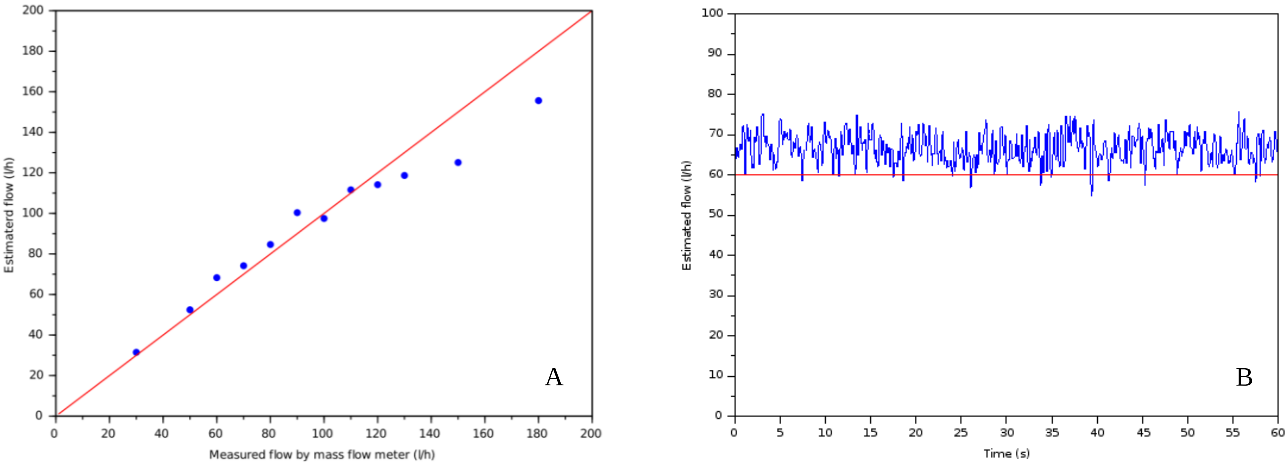

Figure 2. Methane flow estimation (blue) and reference (red) at the laboratory: (A), Mean flow estimation for several leakage rates; (B), Instantaneous flow estimation for one leakage rate.

On-site validation

Figure 3 shows for one leak the gas flow estimation given by the infrared camera and the bagging technique. The mean flow estimation was 38 l/h for the infrared technique and 51 l/h for the bagging technique. By extrapolating the measurements to one year, this leak represents 332 NM^3 of methane, corresponding to less than 0.1% of the annual production of the installation considered.

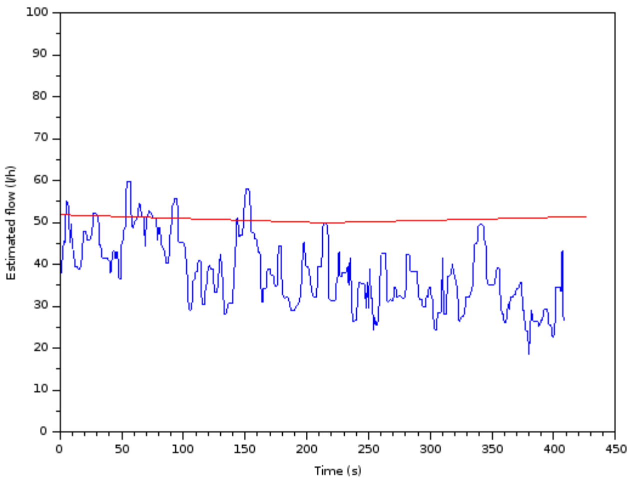

Figure 3. Infrared measurement (blue) and bagging technique (red) for one leak at biogas plant.

CONCLUSIONS

In this study, a novel infrared methane flow estimation technique was presented for biogas leaks measurements. The method was developed and validated through controlled laboratory experiments and on-site measurements. Results showed that our method provided very accurate estimations when the gas cloud displacements in the images are not too large and with sufficient thermal contrast between gas and background. Further developments will tackle large displacement and thermal contrast issues, and improve on-site measurement context. On-site measurements confirmed the ability of the technique to estimate biogas leak with encouraging accuracy. Process of all detected leaks of an installation is currently in progress to provide the overall emission rate for one typical biogas plant.

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